Lecture 22

Using Classes Effectively

Recall: The __init__ Method

two underscores

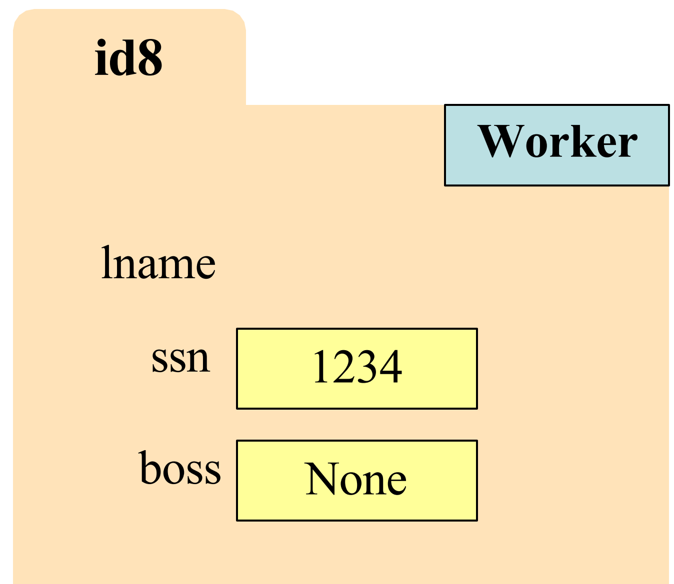
```
w = Worker('Obama', 1234, None)
```

```
def __init__(self, n, s, b):
    """Initializer: creates a Worker

    Has last name n, SSN s, and boss b

    Precondition: n a string,
    s an int in range 0..999999999,
    b either a Worker or None. """
    self.lname = n
    self.ssn  = s
    self.boss = b
```

Called by the constructor



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    Precondition: n a string,
    s an int in range 0..999999999,
    b either a Worker or None. """
    self.lname = n
    self.ssn  = s
    self.boss = b
```

Are there other special methods that we can use?

Example: Converting Values to Strings

str() Function

- **Usage**: str(<expression>)
  - Evaluates the expression
  - Converts it into a string
- How does it convert?
  - str(2) → '2'
  - str(True) → 'True'
  - str('True') → 'True'
  - str(Point3()) → '(0.0,0.0,0.0)'

repr() Function

- **Usage**: repr(<expression>)
  - Evaluates the expression
  - Converts it into a string
- How does it convert?
  - repr(2) → '2'
  - repr(True) → 'True'
  - repr('True') → "'True'"
  - repr(Point3()) → "<class 'Point3'> (0.0,0.0,0.0)"

What Does str() Do On Objects?

- Does **NOT** display contents

  ```
  >>> p = Point3(1,2,3)
  >>> str(p)
  '<Point3 object at 0x1007a90>'
  ```

- Must add a special method
  - __str__ for str()
  - __repr__ for repr()
- Could get away with just one
  - repr() requires __repr__
  - str() can use __repr__
    (if __str__ is not there)

```
class Point3(object):
    """Class for points in 3d space"""
    …
    def __str__(self):
        """Returns: string with contents"""
        return '('+str(self.x) + ',' +
                    str(self.y) + ',' +
                    str(self.z) + ')'

    def __repr__(self):
        """Returns: unambiguous string"""
        return str(self.__class__)+
                str(self)
```

What Does str() Do On Objects?

- Does **NOT** display contents

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>>> p = Point3(1,2,3)
>>> str(p)
'<Point3 object at 0x1007a90>'
```

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    """Class for points in 3d space"""
    …
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                    str(self.y) + ',' +
                    str(self.z) + ')'

    def __repr__(self):
        """Returns: unambiguous string"""
        return str(self.__class__)+
                    str(self)
```

Gives the class name

__repr__ using __str__ as helper

Exercise: str and repr

```
class Example(object):
    """A simple class"""

    def __init__(self,x):
        self.x = x

    def __str__(self):
        return 'Value '+str(self.x)

    def __repr__(self):
        return 'Example['+str(x)+']'
```

```
>>> a = Example(3)
>>> str(a) # a.__str()__
```

What is the result?

A: '3'

B: 'Value 3'

C: 'Example[3]'

D: **Error**

E: I don't know

Exercise: str and repr

```
class Example(object):
    """A simple class"""

    def __init__(self,x):
        self.x = x

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        return 'Value '+str(self.x)

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>>> a = Example(3)
>>> str(a)
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What is the result?

A: '3'

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```

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>>> a = Example(3)
>>> repr(a)
```

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A: '3'

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Exercise: str and repr

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class Example(object):
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    def __init__(self,x):
        self.x = x

    def __str__(self):
        return 'Value '+str(self.x)

    def __repr__(self):
        return 'Example['+str(x)+']'
```

No self

```
>>> a = Example(3)
>>> repr(a)
```

What is the result?

A: '3'

B: 'Value 3'

C: 'Example[3]'

D: **Error**

E: I don't know

Designing Types

From first day of class!

- **Type**: set of values and the operations on them
  - int: (**set**: integers; **ops**: +, –, *, //, …)
  - Time (**set**: times of day; **ops**: time span, before/after, …)
  - Worker (**set**: all possible workers; **ops**: hire,pay,promote,…)
  - Rectangle (**set**: all axis-aligned rectangles in 2D;
    ops: contains, intersect, …)
- To define a class, think of a *real type* you want to make
  - Python gives you the tools, but does not do it for you
  - Physically, any object can take on any value
  - Discipline is required to get what you want

Making a Class into a Type

1. Think about what values you want in the set
   - What are the attributes? What values can they have?
2. Think about what operations you want
   - This often influences the previous question

- To make (1) precise: write a *class invariant*
  - Statement we promise to keep true **after every method call**
- To make (2) precise: write *method specifications*
  - Statement of what method does/what it expects (preconditions)
- Write your code to make these statements true!

Planning out a Class

```
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59"""

    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""

    def increment(self, hours, mins):
        """Move time hours and mins
        into the future.
        Pre: hours int >= 0; mins in 0..59"""

    def isPM(self):
        """Returns: True if noon or later."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Time instance.

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Planning out a Class

```
class Rectangle(object):
    """Class to represent rectangular region

    Inv: t (top edge) is a float
    Inv: l (left edge) is a float
    Inv: b (bottom edge) is a float
    Inv: r (right edge) is a float
    Additional Inv: l <= r and b <= t."""

    def __init__(self, t, l, b, r):
        """The rectangle [l, r] x [t, b]
        Pre: args are floats; l <= r; b <= t"""

    def area(self):
        """Return: area of the rectangle."""

    def intersection(self, other):
        """Return: new Rectangle describing
           intersection of self with other."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

Method Specification

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    Additional Inv: l <= r and b <= t."""

    def __init__(self, t, l, b, r):
        """The rectangle [l, r] x [t, b
        Pre: args are floats; l <= r; b

    def area(self):
        """Return: area of the rectangle."""

    def intersection(self, other):
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           intersection of self with other."""
```

Special invariant **relating** attributes to each other

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Planning out a Class

```
class Hand(object):
    """Instances represent a hand in cards.

    Inv: cards is a list of Card objects.
    This list is sorted according to the
    ordering defined by the Card class."""

    def __init__(self, deck, n):
        """Draw a hand of n cards.
        Pre: deck is a list of >= n cards"""

    def isFullHouse(self):
        """Return: True if this hand is a full
        house; False otherwise"""

    def discard(self, k):
        """Discard the k-th card."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Implementing a Class

- All that remains is to fill in the methods. (All?!)
- When **implementing methods**:
  1. Assume preconditions are true
  2. Assume class invariant is true to start
  3. Ensure method specification is fulfilled
  4. Ensure class invariant is true when done
- Later, when **using the class**:
  - When calling methods, ensure preconditions are true
  - If attributes are altered, ensure class invariant is true

Implementing an Initializer

```
def __init__(self, hour, min):
    """The time hour:min.
    Pre: hour in 0..23; min in 0..59"""
```

This is true to start

```
    self.hour = hour
    self.min = min
```

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Implementing a Method

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This is true to start

```
def increment(self, hours, mins):
    """Move this time <hours> hours
    and <mins> minutes into the future.
    Pre: hours [int] >= 0; mins in 0..59"""
```

What we are supposed to accomplish

This is also true to start

```
    self.min  = self.min + mins
    self.hour = self.hour + hours
```

?

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Implementing a Method

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

```
def increment(self, hours, mins):
    """Move this time <hours> hours
    and <mins> minutes into the future.
    Pre: hours [int] >= 0; mins in 0..59"""
```

What we are supposed to accomplish

This is also true to start

```
    self.min  = self.min + mins
    self.hour = (self.hour + hours +
                 self.min // 60)
    self.min  = self.min % 60
    self.hour = self.hour % 24
```

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Object Oriented Design

Interface

- How the code fits together
  - interface btw programmers
  - interface btw parts of an app
- Given by **specifications**
  - Class spec and invariants
  - Method specs and preconds
  - Interface is **ALL of these**

Implementation

- What the code actually does
  - when create an object
  - when call a method
- Given by method **definitions**
  - Must meet specifications
  - Must not violate invariants
  - But otherwise flexible

Important concept for making large software systems

Implementing a Class

- All that remains is to fill in the methods. (All?!)
- When **implementing methods**:
  1. Assume preconditions are true
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- Later, when **using the class**:
  - When calling methods, ensure preconditions are true
  - If attributes are altered, ensure class invariant is true

Recall: Enforce Preconditions with assert

```
def anglicize(n):
    """Returns: the anglicization of int n.
    Precondition: n an int, 0 < n < 1,000,000"""
    assert type(n) == int, str(n)+' is not an int'
    assert 0 < n and n < 1000000, repr(n)+' is out of range'
    # Implement method here...
```

Check (part of) the precondition

(Optional) Error message when precondition violated

Enforce Method Preconditions with assert

```
class Time(object):
    """Class to represent times of day."""

    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert type(hour) == int
        assert 0 <= hour and hour < 24
        assert type(min) == int
        assert 0 <= min and min < 60

    def increment(self, hours, mins):
        """Move this time <hours> hours
        and <mins> minutes into the future.
        Pre: hours is int >= 0; mins in 0..59"""
        assert type(hour) == int
        assert type (min) == int
        assert hour >= 0
       assert 0 <= min and min < 60
```

Inv: hour is an int in 0..23
Inv: min is an int in 0..59"""

Initializer creates/initializes all of the instance attributes.

Asserts in initializer guarantee the initial values satisfy the invariant.

Asserts in other methods enforce the method preconditions.

Hiding Methods From Access

- Hidden methods
  - start with an **underscore**
  - do not show up in help()
  - are meant to be **internal** (e.g. helper methods)
- But they are **not restricted**
  - You can still access them
  - But this is bad practice!
  - Like a precond violation
- Can do same for attributes
  - Underscore makes it hidden
  - Only used inside of methods

```
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59"""

    def _is_minute(self,m):
        """Return: True if m valid minute"""
        return (type(m) == int and
                m >= 0 and m < 60)

    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert self._is_minute(m)
        ...
```

Helper

Hiding Methods From Access

- Hidden methods
  - start with an **underscore**
  - do not show up in help()
  - are meant to be **internal** (e.g. helper methods)
- But they are **not restricted**
  - You can still access them
  - But this is bad practice!
  - Like a precond violation
- Can do same for attributes

Will come back to this

```
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
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    def _is_minute(self,m):
        """Return: True if m valid minute"""
        return (type(m) == int and
                    m >= 0 and m < 60)

    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert self._is_minute(m)
        ...
```

HIDDEN

Helper

Enforcing Invariants

```
class Time(object):
    """Class to repr times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59
    """
```

Invariants: Properties that are always true.

- These are just comments!

  `>>> t = Time(2,30)`

  `>>> t.hour = 'Hello'`

- How do we prevent this?

- **Idea**: Restrict direct access
  - Only access via methods
  - Use asserts to enforce them
- **Example**:

```
def getHour(self):
    """Returns: the hour"""
    return self.hour

def setHour (self,value):
    """Sets hour to value"""
    assert type(value) == int
    assert value >= 0 and value < 24
    self.numerator = value
```

Data Encapsulation

- **Idea**: Force the user to only use methods
- Do not allow direct access of attributes

Setter Method

- Used to change an attribute
- Replaces all assignment statements to the attribute
- **Bad**:

```
>>> t.hour = 5
```

- **Good**:

```
>>> t.setHour(5)
```

Getter Method

- Used to access an attribute
- Replaces all usage of attribute in an expression
- **Bad**:

```
>>> x = 3*t.hour
```

- **Good**:

```
>>> x = 3*t.getHour()
```

Data Encapsulation

```
class Time(object):
    """Class to repr times of day. """

    def getHour (self):
        """Returns: hour attribute"""
        return self._hour

    def setHour(self, h):
        """ Sets hour to h
        Pre: h is an int in 0..23"""
        assert type(h) == int
        assert 0 <= h and h < 24
        self._hour = d
```

Getter

Setter

NO ATTRIBUTES in class specification

Method specifications describe the attributes

Setter precondition is same as the **invariant**

Data Encapsulation

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        return self._hour

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```

NO ATTRIBUTES
in class specification

Method specifications
describe the attributes

Setter precondition is same as the **invariant**

Getter

Setter

Hidden attribute user should **NOT** know about

Encapsulation and Specifications

```
class Time(object):
    """Class to represent times of day. """

    ### Hidden attributes
    # Att _hour: hour of the day
    # Inv: _hour is an int in 0..23
    # Att _min: minute of the hour
    # Inv: _min is an int in 0..59
```

No attributes in class spec

These comments make it part of the **class invariant** but not part of the (public) **interface**

These comments do not go in help()

Class Invariant vs Interface

Class Invariant

- List attributes that are present
  - Both hidden AND unhidden
  - Lists the invariants of each
- For the **implementer**
  - Guide for the initializer
  - Guide for method definitions

Interface

- Describes what is accessible
  - Unhidden methods/attribs
  - What is visible in help()
- For user/**other programmers**
  - Enough to create an object
  - Enough to call the methods

Early years of CS1110
confused these two topics

Mutable vs. Immutable Attributes

Mutable

- Can change value directly
  - If class invariant met
  - **Example:** turtle.color
- Has both getters and setters
  - Setters allow you to change
  - Enforce invariants w/ asserts

Immutable

- Can't change value directly
  - May change "behind scenes"
  - **Example:** turtle.x
- Has only a getter
  - No setter means no change
  - Getter allows limited access

May ask you to differentiate on the exam

Mutable vs. Immutable Attributes

Mutable

- Can change value directly
  - If class invariant met
  - **Example:** turtle.color
- Has both getters and setters
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Where?

Thursdays

Immutable

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  - May change "behind scenes"
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May ask you to differentiate on the exam